

BELLCOMM, INC.

1100 Seventeenth Street, N.W. Washington, D. C. 20036

SUBJECT: Passive Microwave Sensors Available
for Meteorology and Earth Resources
Remote Sensing - Case 710

DATE: May 2, 1968

FROM: B. E. Sabels
W. L. Smith

ABSTRACT

This memorandum was originally prepared for use at the 9th Passive Microwave Team Meeting, February 29, 1968 at MSC. It summarizes the requirements for sensing in Meteorology and Earth Resources and lists existing passive microwave systems, both within NASA and throughout the industry. A shopping list of about 40 microwave systems is offered.

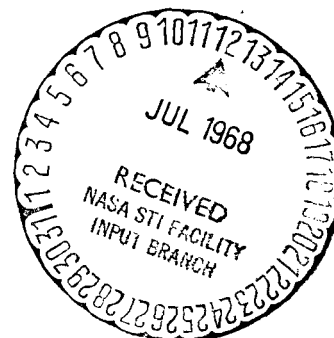
(NASA-CR-95476) **PASSIVE MICROWAVE SENSORS
AVAILABLE FOR METEOROLOGY AND EARTH
RESOURCES REMOTE SENSING (Bellcomm, Inc.)**
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MEMORANDUM FOR FILE

1. INTRODUCTION

This paper is written in support of the objectives of the 9th Passive Microwave Team Meeting, MSC, Houston, February 29 - March 1, 1968. The objectives of this meeting are a) to define the role of passive microwave sensing in the user disciplines of Meteorology and Earth Resources; b) to discuss existing systems and sensing capabilities and c) to suggest a microwave sensor complement for immediate and future use in low and high flying aircraft.

Passive microwave radiometers and a 9 Ghz, (Autonetics) microwave imager have been part of the Earth Resources sensor package onboard NASA aircraft. The equipment, itemized below, has been operated, more or less successfully, to measure test site features of interest to scientists and user agencies. The major problem which had to be overcome with the MR 62 and MR 64 radiometers was data handling and interpretation. The Autonetics imaging system used has not produced any satisfactory imagery.

Several radiometers and imagers are available for selection so as to optimize the value of microwave data returned. In the following, sensing objectives and equipment available will be discussed in detail.

2. OBJECTIVES AND REQUIREMENTS OF PASSIVE MICROWAVE SENSING

A. Meteorology

Major meteorological passive microwave applications deal with the study of global atmospheric structure and with lower atmospheric boundary conditions. A specific item of study is atmospheric temperature, applying radiance inversion techniques in fringe zones of oxygen absorption bands at 50-55 Ghz; cloud top temperatures, cloud water, precipitation, roughness, soil moisture, surface water, and ice and/or snow burden, using the radiance at 19 Ghz coupled with scanning capabilities.

B. Earth Resources

The major earth resources passive microwave application to date is the delineation of sea/ice interfaces, sea state, precipitating clouds, water/snow/land interfaces, surface roughness, and

compositional mapping. Other applications are the determination of land use, snow and glacier inventory, major crop and forest inventory, and soil classification. Instrumentation used for these purposes includes 19.35 Ghz scanning radiometers and sensors in the 0.4 to 95 Ghz range.

C. SENSING REQUIREMENTS

The major requirements in Meteorology are for high accuracy in Kelvin temperature determination with limited resolution, while in Earth Resources areal resolution requirements are most critical. Instruments such as the Staelin Microwave Temperature Sounder (S-104), operating from orbital altitude, would monitor temperature levels at 4 and 10 km altitude over a swath width corresponding to 50 nm on the ground. Instruments such as the Thaddeus Scanning Microwave Radiometer (S-075) would typically cover a swath of 335 nm from orbital altitude, with a resolution of 8x7 nm. Such large resolution cells would be a serious limitation to Earth Resources applications, and the increase of ground resolution must be pointed out as a major R&D goal. Such increase can be accomplished by a) choice of a shorter operating wavelength, or b) increase in antenna size. The problems related to the development of passive microwave technology for application in Earth Resources sensing should be given considerable attention by such NASA centers as MSC and possibly ERC and GSFC.

3. EXISTING PASSIVE MICROWAVE SYSTEMS

A. NASA Operated Systems

MR 62 and MR 64

The NASA Earth Resources aircraft has so far flown successfully two microwave instruments, which are the MR 62 and MR 64 radiometers. In addition, a scanning radiometer built by Space General Corp. to the specifications of GSFC for meteorological studies during the Nimbus series was flown onboard the Convair 990 operated by NASA out of ARC. This instrument is generally known as the Thaddeus imager. The NASA instruments just described have operating characteristics as outlined in Table 1.

The MR 62 and MR 64 instruments were built by JPL for microwave measurements in planetary flyby missions of the Mariner series during 1962 and 1964 respectively. The frequencies of 15.8 and 22.2 Ghz for the MR 62 radiometer were selected for the study of water vapor in the atmosphere of Venus. The 22.2 Ghz band is located in a water absorption band, while the 15.8 Ghz band is located outside any absorption bands. For the MR 64, the frequencies of 34.0 and 9.2 Ghz were selected for temperature measurements on and below the surface of Mars. For earth sensing, the 34.0 Ghz band is useful, being located in a window between O_2 and H_2O absorption bands.

The 9.2 Ghz channel is in a region of commercial weather radar and suffers from interference. All in all, the two instruments designed for remote sensing on Venus and Mars have, after some modifications, done rather well in Earth Resources sensing. This is indicated in the data sample of Figure 1, obtained by aircraft microwave radiometer MR-62, on channels 15.8 Ghz and 22.2 Ghz, where it is seen that lithologic variations and terrain features such as a lake (at 68-70 sec.) modify the signal sufficiently to be identifiable.

Nimbus (Thaddeus) Imager

The Nimbus ("Thaddeus") phased array scanning radiometer was built by Space General Corporation for specific meteorological studies, such as the mapping of cloud top temperatures and precipitation distribution, from unmanned spacecraft. The instrument has so far never been used in space. It was flown successfully onboard the ARC Convair 990 and produced imagery of the California coastline, the city of St. Louis and other places. The Kelvin temperature data points have been converted to a 60-shade color scale, and the resulting color imagery has been reproduced and has become widely known. Some calibration problems are presently being worked on, and the Thaddeus imager or a copy thereof must be considered as one potentially useful imaging system for aircraft R&D missions within the realm of Earth Resources remote sensing.

Autonetics Imager

The Autonetics microwave imager which has been a part of the NASA aircraft Earth Resources package has failed to produce imagery of sufficient quality to be useful for Earth Resources remote sensing.

B. OTHER MICROWAVE SYSTEMS

General

The state-of-the-art of passive microwave sensing has been compiled by Ewen (1). Table 2, which contains a summary of microwave R&D efforts, is based on material gathered by Dr. Ewen. According to this table, meteorological interest centers in the 22 Ghz region (H_2O bands), with other areas located at 50-55 Ghz (O_2 fringe), 60-64 Ghz (O_2 fringe), 101 Ghz (O_3 fringe) and 19 Ghz (clouds). Oceanographic interest is indicated at 10, 15 and 60 Ghz. Earth Resources interest, significantly, is indicated in the region 1-300 Ghz, with individual interest at 1.4, 9-10, 15, 18, 19, 32, 34, 35, 85 and 95 Ghz.

In the following, several systems of microwave sensing equipment will be identified which are either under NASA procurement or are potentially available on short order for use in remote sensing programs.

Recent Earth Resources Procurement

A five channel microwave radiometer system is being procured by the NASA Earth Resources Survey Program for use in the Lockheed P3A aircraft. The frequencies chosen are 1.42, 10.25, 22.235, 22.355, and 32.4 Ghz. Therefore, the objective of the system will be a study of the microwave properties of both the atmosphere and the ground. The 1.42 and 10.25 Ghz channels are expected to measure surface and subsurface temperatures, while the 22.235, 22.255 and 32.4 Ghz channels will monitor atmospheric water content and temperature. The system is being built by Space General Corp. and will be operational in late 1968. It is suitable for operation under vacuum conditions.

Contractor Shelf Inventoriesa) Space General

Microwave systems which have been built for inhouse studies or under contract are listed in Table 3. All of these systems are available as copies within a time frame of about five months. Also, Space General Corp. maintains a truck-based field unit containing boom-mounted 1.2, 13.4, 37 and 94 Ghz polarized radiometers and data trailer (Figure 2). A typical data return of the 13.4 and 37 Ghz channels is given in Figure 3. The sensors have been applied to ground water, soil moisture, composition and thermal studies. Space General has supplied microwave sensors for military ground surveys, high altitude nuclear blast detection, commercial exploration, and space application.

b) Sperry Microwave Electronics Company

Microwave Systems which have been built by Sperry are listed in Table 4. The systems include the AN/AAR-33 radio-metric mechanically scanning search set for icebergs flown by the U. S. Coast Guard onboard a C-130 aircraft, and company-funded 50-60 Ghz meteorological radiometers for atmospheric temperature studies. Other noteworthy systems are x-band systems and 68-70 Ghz mechanically scanning microwave surveillance sets and classified thermal radiation detectors. Sperry has a 15 year history in microwave technology and supports an active atmospheric physics laboratory at the Sudbury, Massachusetts, Sperry Research Center.

c) Ryan Aeronautical Company

Microwave equipment under development by the company is listed in Table 5. Ryan has so far specialized in active radar and altimeter equipment and is recently making an effort to support the Earth Resources Program. The 13.7 and 31 Ghz radiometers will be available in late 1968. The 13.5 Ghz imager will be on the market by the end of the year.

d) North American Aviation

Recently, NAA has engaged in an effort to produce several microwave radiometers. The equipment will probably not be available until 1969. No firm specifications are available as yet.

4. SUGGESTIONS FOR FUTURE SYSTEMS

The review of the state of microwave technology given above suggests that an abundance of specialized microwave systems exist which so far has been used and advanced only by the meteorological remote sensing program of NASA. Commercial Earth Resources interests have also explored microwave sensing, but few of such studies have become known. The NASA Earth Resources microwave sensing effort has so far lacked instrumentation designed for its specialized task, and has made the most of planetary and other surplus.

A microwave study program of earth resources from aircraft and spacecraft requires that the microwave properties of the atmosphere and its lower boundary are known. Therefore, the inclusion of meteorological microwave sensors in Earth Resources payloads is a necessity. However, it cannot be expected that a single radiometer or scanner tuned to monitor the net surface microwave radiation will suffice to satisfy the requirements of a number of earth resources disciplines and objectives.

A multiplicity of radiometers and imagers should be considered for the study of earth resources. Because such disciplines as agriculture and geology are concerned with relatively small targets, microwave instruments must, for the present, be flown at relatively low aircraft altitudes to compensate for the generally poor resolution characteristics. It is hoped that advances in antenna technology will permit the same sensors to be used from high, possibly orbital altitudes. At present the effects of polarization on the information content of radiometry are being studied, and microwave sensor systems specialized for one user discipline (oceanography, geology) are being considered.



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Attachments

References

Tables 1-5b

Figures 1-3

REFERENCES

1. M. I. Ewen, State of the art of microwave and millimeter wave radiometric sensors, International Symposium on Electromagnetic Sensing of the Earth from Satellites, Miami Beach, November 22-24, 1965.

TABLE 1

NASA Operated Passive Microwave Sensors

<u>System</u>	<u>f(Ghz)</u>	<u>λ(CM)</u>	<u>polarization</u>	<u>sensitivity</u> <u>°K/sec</u>	<u>3dB beam width</u>	
					<u>vertical</u>	<u>horizontal</u>
MR 62	22.2	1.3	dual	3.7	2.2°	1.8°
	15.8	1.9		1.3	3.0°	3.0°
MR 64	34.0	.88		3.4	1.15°	1.25°
	9.2	3.3		10.3	3.8°	3.4°
Space General Nimbus- GSFC	19.35	1.5	single	1	0.8° to 5°	
Autonetics	8.9 - 9.9	3	-	1.5	3° x 4°	

TABLE 2

SUMMARY OF PASSIVE MICROWAVE R&D EFFORTS

(After M.I. Ewen, Ref.(1))

DISCIPLINE	INVESTIGATOR	AFFILIATION	FREQUENCY, Gh ₂	OBJECTIVE	EXPERIMENT BASE	COMMENTS
Meteorology	Staelin	MIT	Near 22	Global H ₂ O	Aircraft, Satellite and ground	JPL data
	Hyatt	Douglas	Near 22	Global H ₂ O	Aircraft	
	Barath	JPL	Near 22	Global H ₂ O	Aircraft	
	Pearson	Boeing	50-55	Atm. temp.	Ground	
	Mount	Sperry	50-55	Atm. temp.	Ground	
	Lenoir	MIT	60-64	Atm. temp.	Satellite	
	Caton	Ewen-Knight	101.8	Global air circ.	Grd. aircraft	Ozone
	Thaddeus	Goddard Inst.	19	Clouds, terr-rain	Aircraft, Sat.	Operational
	MSC-JPL	MSC-JPL	10.2, 22.2, 32.4	H ₂ O, temp., atm. and terr.	Aircraft	in procurement
Oceanography	Ewen	Ewen-Knight	60	Iceberg detection	Satellite	Oxygen
	Campbell	Northrop	10		Aircraft	Operational
	Roeder	Sperry	15		Aircraft	(ISCG)

TABLE 2 (contd)

SUMMARY OF PASSIVE MICROWAVE R&D EFFORTS

DISCIPLINE	INVESTIGATOR	AFFILIATION	FREQUENCY, Gh ₂	OBJECTIVE	EXPERIMENT BASE	COMMENTS
Earth Resources	O'Brien	Mitre	10-300	Atm. effects	-	Analyti- cal
	Kennedy	Ryan	15,35,85	Terrain ident.	Grd., air- craft	dielec- tric prop.
	Edgerton	Space General	1.2, 13, 37, 94	Show, grd., water, ter- rain	Grd., air- craft	Opera- ting (inhouse)
	Porter	Porter	Up to 95	Terrain ident.	Grd.	
	Peake	Ohio State	10	Terrain ident.	Grd.	Moisture effects
	Thaddeus	Goddard Inst.	19	Terrain	Aircraft	Opera- tional
	Barath- Blinn	JPL	9.2, 15.8, 22.2, 34	Terrain ident.	Aircraft	Opera- tional
	MSC-JPL	MSC-JPL	1.4, 10.2, 22.2, 32.4	Atmos. and terrain	Aircraft	in pro- curement

TABLE 3

Space General Microwave Shelf Equipment

Type	f(Ghz)	λ (CM)	polarization	sensitivity (ok/s)	3db beam width
L band	1.257	24	dual	$<1^\circ$	15°
k_e	13.4	2.2		$<1^\circ$	5°
k_a	37	0.8		$<0.5^\circ$	5°
W	94	0.3		$<2^\circ$	5°
k_u	19.35	1.5		$<1^\circ$	$0.8 - 5^\circ$
L	0.6-1.8	50-15	single	$<2^\circ$	20°
Tracker mapper	37	0.8	dual	$<0.5^\circ$	2°
Tracker mapper	94	0.3		$<2^\circ$	2°
K_u imager	19.35	1.5	dual	$<1^\circ$	$0.8 - 5^\circ$
k_e	13.4	2.2	dual	1°	0.5°
k_a	37	0.8			
W	94	0.3			

DASA

System

TABLE 4

Sperry Microwave Shelf Equipment

Type	f(Ghz)	Overall Noise (db)
N.O.L.	34-36	8.7
N.O.L.	37	airborne scanner, stabilized parabolic antenna and radome
	35	tactical guidance radiometer, parabolic, dual pol. 11.5 db - 12 inch parabolic antenna
	35	radiometer tactical measurements program 8 db - 36 ft parabolic antenna
U.S.C.G.	13.5-16.5	radiometric search set dual pol. 8.9 db, 2.2 x 1.7° beam width, 64 x 91 CM antenna width of search strip 3.65 times altitude
U.S.B.R.L.	68.5	radiometric signature equipment 20db, 1°k/10sec resolution
U.S.A.S.C.	70	surveillance set
S.R.R.C.	50-60	meteorological radiometer, horizontal pol. 14.3 db, 3°k(3db) accuracy, 6 inch parabolic antenna
AFCRC	-	thermal radiation detection

TABLE 5a

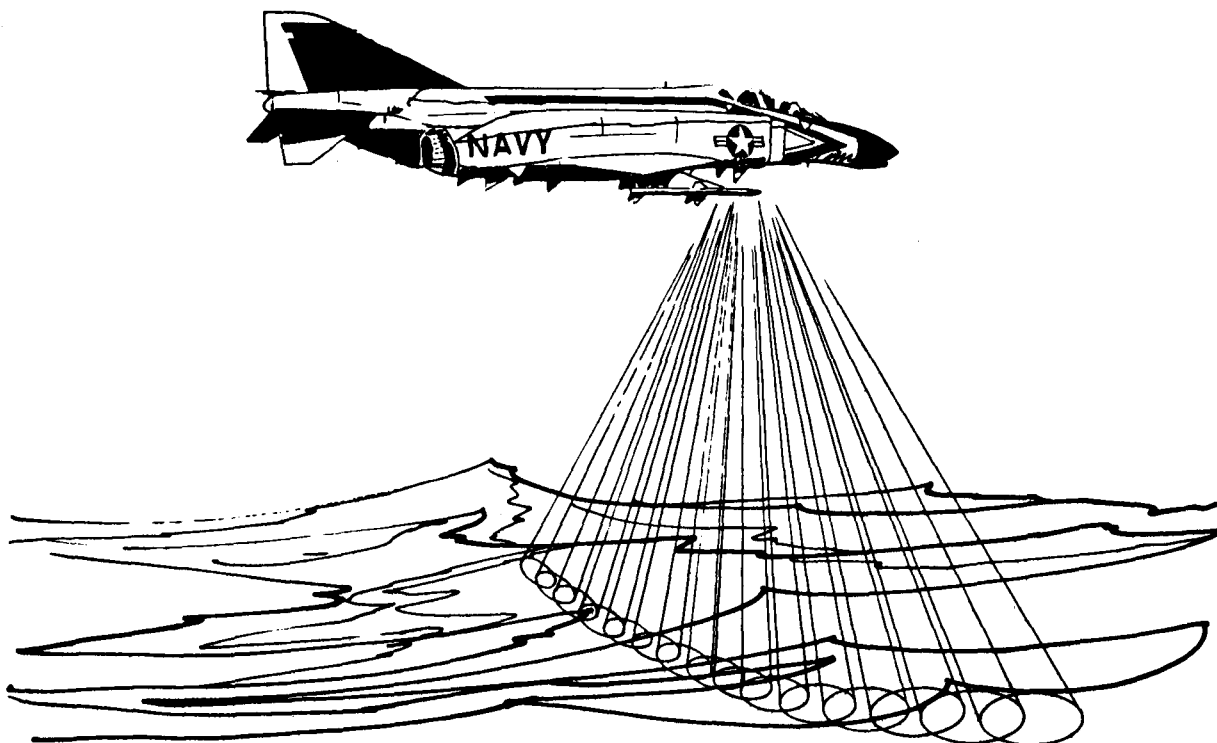
Ryan Microwave Equipment Under Development

<u>f(Ghz)</u>	<u>Beamwidth</u>	<u>Polarization</u>	<u>Sensitivity</u>	<u>Accuracy</u>
13.5 scanner	5°	dual	0.5° - 1° k	<u>+2°</u> k
13.7	5°	dual	1°	<u>+2°</u> k
31.0	5°	dual	1°k	<u>+2°</u> k

Table 5b

RYAN

RYAN 13.5 GHz SCANNING RADIOMETER



CHARACTERISTICS

● PHYSICAL

Electronics Size - 1 Ft.³
 Electronics Weight - 100 Lbs.
 Electronics Power - 200 Watts
 Data Bandwidth - 10 kHz
 Antenna Size - 9 In. x 9 In. x 2 In.
 Antenna Weight - 30 Lbs.
 Antenna Mount Size - 1 Ft. x 1 Ft.
 Antenna Weight - 20 Lbs.

● COVERAGE

Scanning Look Angle - +45°
 Beamwidth - 5°
 Resolution, Variable - 10 Ft. x 10 Ft. and Up
 Polarizations - V and H
 Sensitivity - (.5°→1°) K
 Accuracy - +2° K

● CAPABILITIES

Altitude - 5,000 to 30,000 Ft.
 Velocity - 300 to 550 mph
 Roll - +5°
 Pitch - +10°
 Yaw - +5°
 ΔT - 1° K

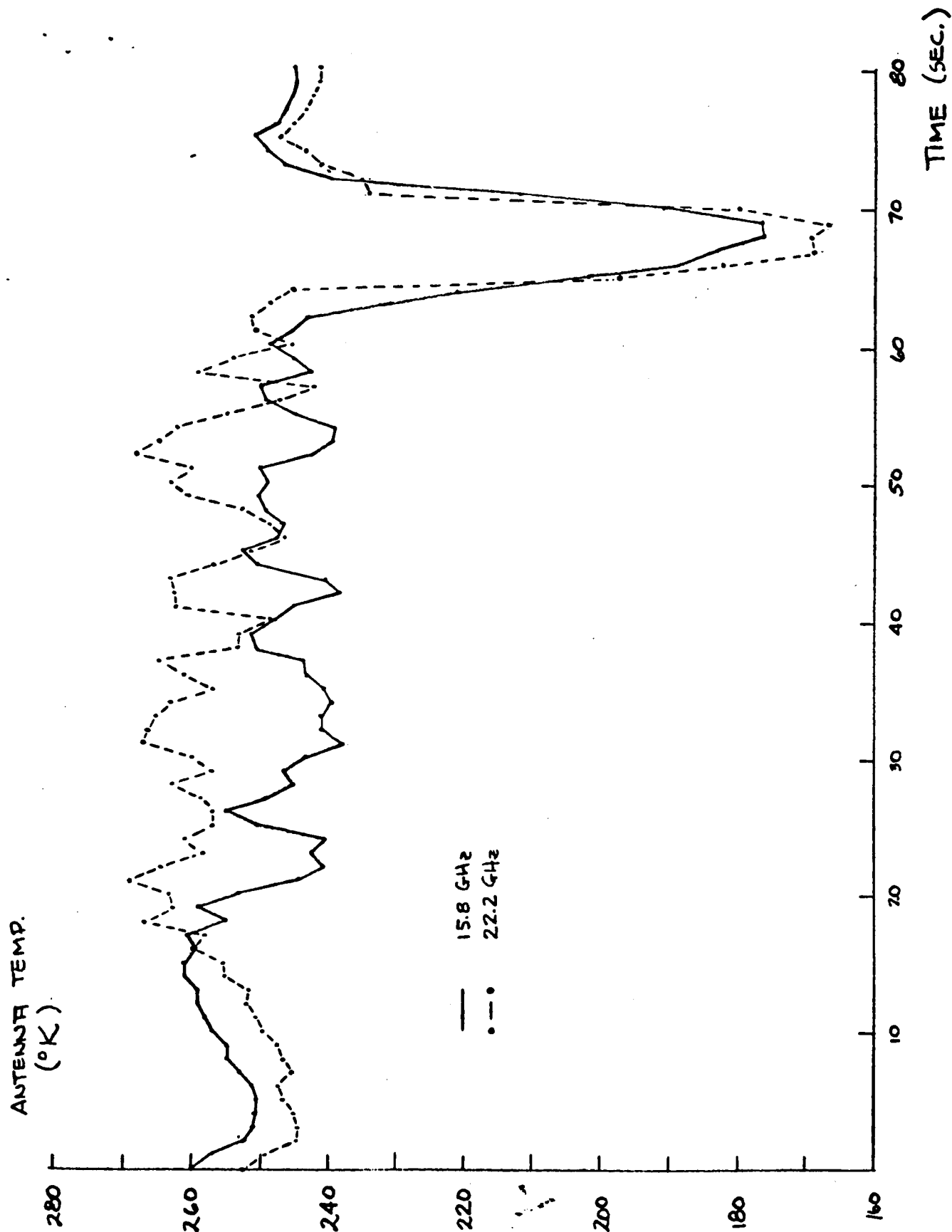
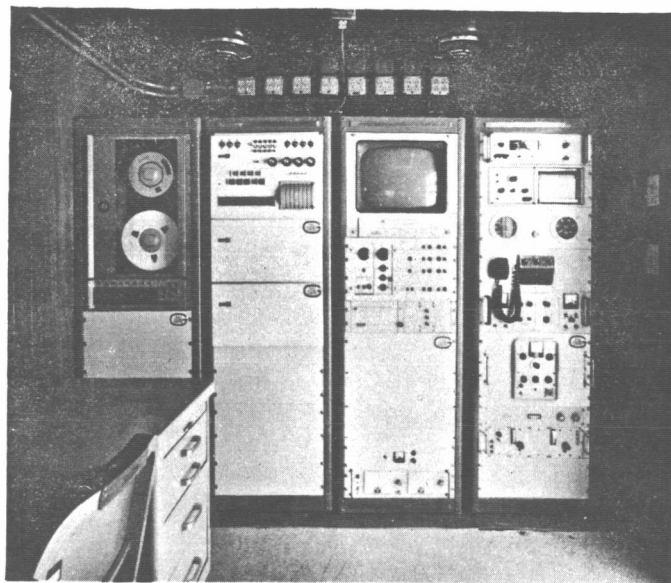
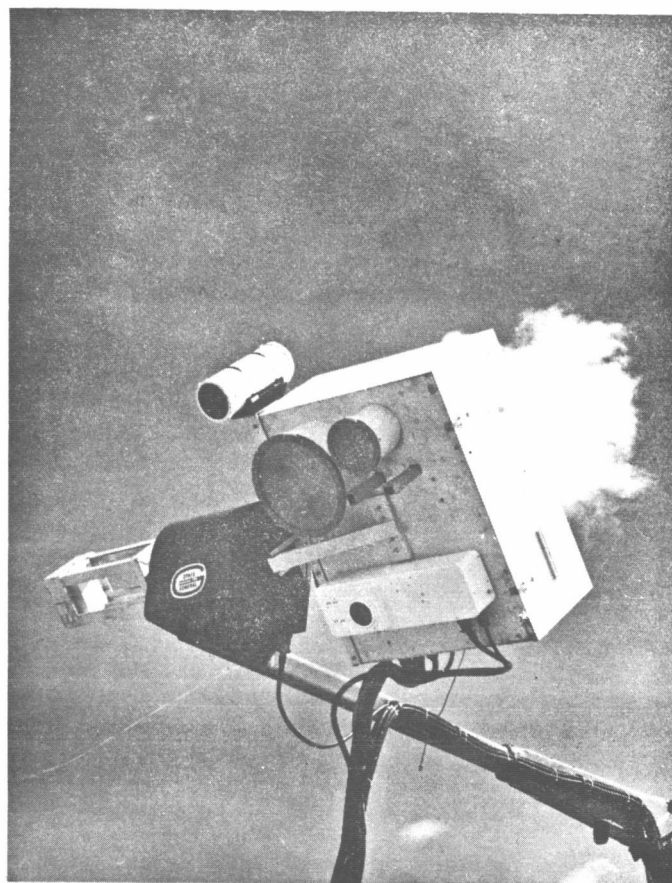


Figure 1

Sample of field data obtained from aircraft microwave Radiometer MR-62 showing antenna temperatures on channels 15.8 GHz and 22.2 GHz; Mission 29, Flight 3, Line 1, Run 1, E-10°



INTERIOR OF FIELD TRAILER



CLOSEUP VIEW OF MICROWAVE RADIOMETERS

<u>Parameter</u>		<u>Radiometer</u>	
Center Frequency	13.4 GHz	37 GHz	94 GHz
Sensitivity	1.0°K/sec	0.5°K/sec	2.0°K/sec
Antenna Beamwidth	5°	5°	9°
Antenna Types	Lens-Horn	Lens-Horn	Long Horn
Calibration Capability	±1°K	±1°K	±1°K
Integration Period	.5 to 15 seconds (all radiometers)		

The accessory equipment also attached on the common mounting plate consists of a 35 mm Robot camera and a COHU T.V. camera.

FIGURE 2 - SPACE GENERAL FIELD EQUIPMENT

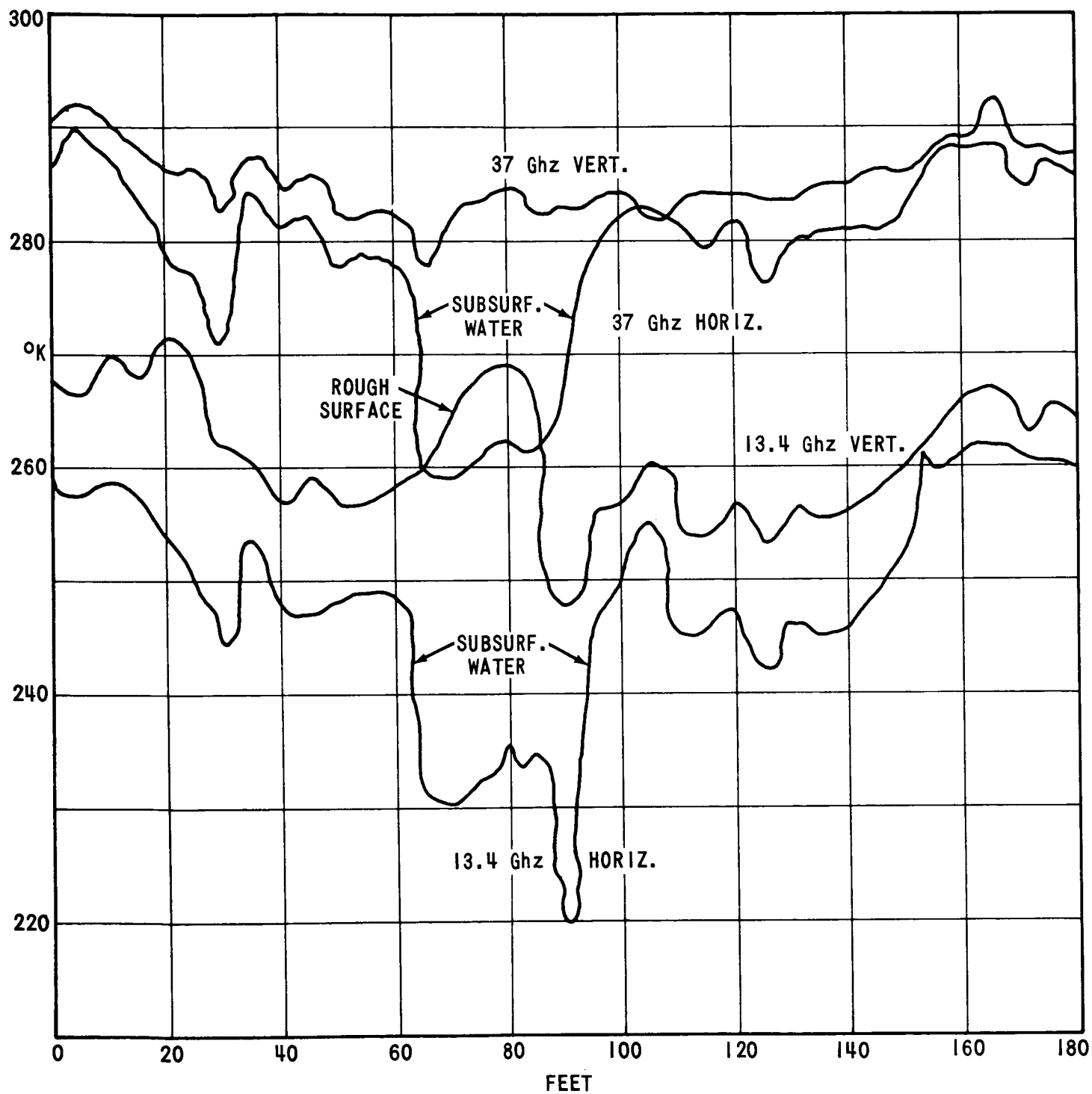


FIGURE 3 - MULTIFREQUENCY PASSIVE MICROWAVE SUBSURFACE WATER SURVEY, SPACE GENERAL CORP. WATER BODY SHOWS UP ONLY IN HORIZONTAL POLARIZATION. LOWER FREQUENCY SURVEY SHOWS BETTER PENETRATION OF UNDERGROUND MICROWAVE ENERGY

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